Increasing Accuracy in Computed Inviscid Boundary Conditions

Accuracy is increased through use of higher-order time derivatives.

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A technique has been devised to increase the accuracy of computational simulations of flows of inviscid fluids by increasing the accuracy with which surface boundary conditions are represented. This technique is expected to be especially beneficial for computational aeroacoustics, wherein it enables proper accounting, not only for acoustic waves, but also for vorticity and entropy waves, at surfaces.

Heretofore, inviscid nonlinear surface boundary conditions have been limited to third-order accuracy in time for stationary surfaces and to first-order accuracy in time for moving surfaces. For steady-state calculations, it may be possible to achieve higher accuracy in space, but high accuracy in time is needed for efficient simulation of multiscale unsteady flow phenomena. The present technique is the first surface treatment that provides the needed high accuracy through proper accounting of higher-order time derivatives.

The present technique is founded on a method known in art as the Hermitian modified solution approximation (MESA) scheme. This is because high time accuracy at a surface depends upon, among other things, correction of the spatial cross-derivatives of flow variables, and many of these cross-derivatives are included explicitly on the computational grid in the MESA scheme. (Alternatively, a related method other than the MESA scheme could be used, as long as the method involves consistent application of the effects of the cross-derivatives.)

While the mathematical derivation of the present technique is too lengthy and complex to fit within the space available for this article, the technique itself can be characterized in relatively simple terms: The technique involves correction of surface-normal spatial pressure derivatives at a boundary surface to satisfy the governing equations and the boundary conditions and thereby achieve arbitrarily high orders of time accuracy in special cases. The boundary conditions can now include a potentially infinite number of time derivatives of surface-normal velocity (consistent with no flow through the boundary) up to arbitrarily high order. The corrections for the first-order spatial derivatives of pressure are calculated by use of the first-order time derivative velocity. The corrected first-order spatial derivatives are used to calculate the second-order time derivatives of velocity, which, in turn, are used to calculate the corrections for the second-order pressure derivatives. The process as described is repeated, progressing through increasing orders of derivatives, until the desired accuracy is attained.

This work was done by Roger Dyson of **Glenn Research Center** *and Ray Hixon of the Institute for Computational Mechanics in Propulsion. Further information is contained in a TSP (see page 1).*

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Higher-Order Finite Elements for Computing Thermal Radiation

Computationally efficient methods yield close approximations of exact solutions.

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Two variants of the finite-element method have been developed for use in computational simulations of radiative transfers of heat among diffuse gray surfaces. Both variants involve the use of higher-order finite elements, across which temperatures and radiative quantities are assumed to vary according to certain approximations. In this and other applications, higher-order finite elements are used to increase (relative to classical finite elements, which are assumed to be isothermal) the accuracies of final numerical results without having to refine computational meshes excessively and thereby incur excessive computation times.

One of the variants is termed the radiation sub-element (RSE) method, which, itself, is subject to a number of variations. This is the simplest and most straightforward approach to representation of spatially variable surface radiation. Any computer code that, heretofore, could model surface-to-surface radiation can incorporate the RSE method without major modifications.

In the basic form of the RSE method, each finite element selected for use in computing radiative heat transfer is considered to be a parent element and is divided into sub-elements for the purpose of solving the surface-to-surface radiation-exchange problem. The sub-elements are then treated as classical finite elements; that is, they are assumed to be isothermal, and their view factors and absorbed heat fluxes are calculated accordingly. The heat fluxes absorbed by the sub-elements are then transferred back to the parent element to obtain a radiative heat flux that varies spatially across the parent element. Variants of the RSE method involve the use of polynomials to interpolate and/or extrapolate to approximate spatial variations of physical quantities.

The other variant of the finite-element method is termed the integration method (IM). Unlike in the RSE methods, the parent finite elements are not subdivided into smaller elements, and neither isothermality nor other unrealistic physical conditions are assumed. Instead, the equations of radiative heat transfer are integrated numerically over the parent finite elements by use of a computationally efficient Gaussian inte-